Cooling of the Electron Beam Dump on the Femtosource

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In this analysis we consider dumping of the electron beam at 3.1 GeV. The electron beam parameters are as follows: the normalized emittance in the vertical plane is 0.4 mm-mrad and 20 mm-mrad in the horizontal plane, the average beam current is 10 μA. We also assume that beta-functions at the dump are blown up to ~1000 m. This gives us: $\sigma_y = 0.025$ cm and σ_x =0.18 cm. In what follows we approximate the real beam with a model cylindrical beam with the radius $r_m = 2\sqrt{\sigma_y \sigma_x} = 0.13$ cm and assume that the electron beam power P= 31 kW (3.1 GeV, 10 μA) is uniformly distributed over the area limited by this radius.

We model the dump as a copper cylinder with the radius r_0 =5 cm. We assume that the side wall of the cylinder is cooled by a pressurized water flown at a speed of 6 m/s. In this regime water removes the heat from the copper wall with the rate α=2 $W/(\text{cm}^2 K)$. When applicable we used the following parameters for copper under the temperature of approximately 600 °C: thermal conductivity $\lambda = 3.7\ W/(\text{cm K})$, thermal capacity $c_p = 0.42\ J/(g\,K)$, and density $\rho = 8.93\ g/\text{cm}^3$.

We assume that all electron beam power is uniformly absorbed in the copper along the beam pass on the length L=7X_{rad}, where $X_{\text{rad}} = 1.4$ cm is the radiation length. For a crossection of the area of the heat deposition we assume $\pi(r_m)^2$.

Then we calculate temperature drop in the copper from the beam center to r_m:
$\text{dT}_1 = \frac{P}{4\pi\lambda L} = 69$ °C
and temperature drop from radius r_m to the radius r_0
$\text{dT}_1 = \frac{P}{2\pi\lambda L} \text{Log}_e\left[\frac{r_0}{r_m}\right] = 475$ °C

The temperature drop between copper wall and water is:
$\text{dT}_3 = \frac{P}{2\pi r_0 L \alpha} = 50$ °C

Therefore we get the highest temperature dT= $\text{dT}_1 + \text{dT}_2 + \text{dT}_3 \simeq 600$ °C above the water temperature. This is below the melting temperature of 1083 °C but much above the temperature of the elastic deformations ~ 110 °C. In this case we need to know how many cycles of heating and cooling this dump will survive. In order to do this we applied the following commonly used formulae:
$n_{\text{clycles}} = \frac{U - 50\,T_0}{16.7\,U} \text{Exp}\left[\frac{U}{6\,(T_0 + \text{dT})}\right]$,

where U[cal/mol] is the evaporation coefficient (U=7.6 10^4cal/mol in Cu), T_0 $[K]$ is stationary temperatureand all numerical coefficients are dimensional.

Using $T_0 = 310\,K$ and $\text{dT} = 600$ °C we calculate : $n_{\text{clycles}} \simeq 70000$.

Similar calculations for aluminum (λ=2.3 $W/(\text{cm K})$, X_{rad} = 8.9 cm, U=6 10^5 cal/mol) give :
dT$\simeq$ 190 °C and $n_{\text{clycles}}$$\simeq$3 10^7

This result is mainly due to the more than six times longer radiation length in the aluminum than this is in copper.
Given the fact that the induced radioactivity in the aluminum is about the same as in copper, the aluminum seems to be better material for a dump than copper.